The hot neutron star

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Abstract

In this paper the equation of state of hot neutron matter is calculated. Involving the Oppenheimer-Volkov- Tolman equation global parameters of a neutron star at the finite temperature are obtained. The objective of our work was to study the influence of the temperature on the main parameters of a neutron star.

1 Introduction

This paper is concerned with a neutron star and its macroscopic parameters such as the mass M and the radius R which are influenced by the temperature. Both the mass and the radius as well as the cooling evolution are determined first of all by the equation of state.
Considering the matter of a neutron star one should take into account not only neutrons but as the most elementary model has it neutrons, protons and leptons. This paper presents a basic model of neutron star matter including interactions among nucleons in the Hartree approximation [1][2]. Increasing interest in neutron matter at finite temperature has been observed recently in relation to the problems of hot neutron stars and of protoneutron stars and their evolutions in particular. Theories concerning protoneutron stars are being discussed in works by Prakash et. al. [3]. Some other elements like hyperons, mesons or quarks could be also found in the interior of a neutron star but their relevance is not going to be included in our work.
One can divide this paper into two parts. In the first one thermodynamic properties of Fermi gas, which consists of neutrons, protons and leptons, are examined. The properties of the quark matter at finite temperature were also looked into in [4]. The range of temperatures considered vary from 0-50 MeV. Analytical forms for the pressure, energy density and fermion number density has been calculated in order to solve the OTV equation. Solution of this equation is the main subject of the second part.

2 General Theory

The aim of this paper is to present a rudimentary approach to the equation of state for neutron stars at the finite temperature. In such an approach the neutron star matter consists of electrically neutral plasma which comprises protons, neutrons and electrons. The Lagrange density function in this model is given by

$$\mathcal{L} = i\overline{\psi}\gamma^{\mu}\partial_{\mu}\psi - \bar{\psi}M\psi + v < \bar{\psi}\psi > \bar{\psi}\psi - \frac{1}{2}v < \bar{\psi}\psi >^2 + \\ i\sum_{f=1}^{2}\overline{L_f}\gamma^{\mu}\partial_{\mu}L_f - \sum_{f=1}^{2}g_f(\overline{L}_f H e_{Rf} + h.c.) - \frac{1}{2\kappa}R \tag{1}$$

where $\kappa = 8\pi G/c^4$ and R is the Ricci curvature scalar. The fermion fields are composed of neutrons, protons and electrons, muons and neutrinos

$$\psi = \begin{pmatrix} \psi_n \\ \psi_p \end{pmatrix}, \ L_1 = \begin{bmatrix} \nu_e \\ e^- \end{bmatrix}_L, \ L_2 = \begin{bmatrix} \nu_\mu \\ \mu^- \end{bmatrix}_L, \ e_{Rf} = (e_R^-, \mu_R^-) \tag{2}$$

and the Higgs field H takes the form of

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ V \end{pmatrix} \tag{3}$$

Nucleon masses are given by

$$M = \begin{pmatrix} m_n & 0 \\ 0 & m_p \end{pmatrix} \tag{4}$$

The electron and muon masses equal $m_e = g_1 V/\sqrt{2}, \ m_\mu = g_2 V/\sqrt{2}$ respectively where $V = 240$ GeV. The model describes nuclear interaction in the Hartree approximation for $v \neq 0$ [1]. Introducing the interaction one can obtain the effective nucleon mass

$$M^* = M - v < \bar{\psi}\psi > \tag{5}$$

The constant term appearing in (1)is responsible for the negative pressure

$$P = \frac{1}{2}v < \bar{\psi}\psi >^2 \tag{6}$$

This model is the simple approximation of the relativistic mean filed theory [1]. The equation (5) is a highly nonlinear equation due to the average $< \overline{\psi}\psi >$ which is defined as

$$< \overline{\psi}\psi >= \frac{M^* M^2}{\pi^2}\int_0^\infty \frac{y^2 dy}{\sqrt{y^2+\delta^2}}\{\frac{1}{\exp(\beta(\epsilon_k - \mu)) + 1} + \\ \frac{1}{\exp(\beta(\epsilon_k + \mu)) + 1}\}$$

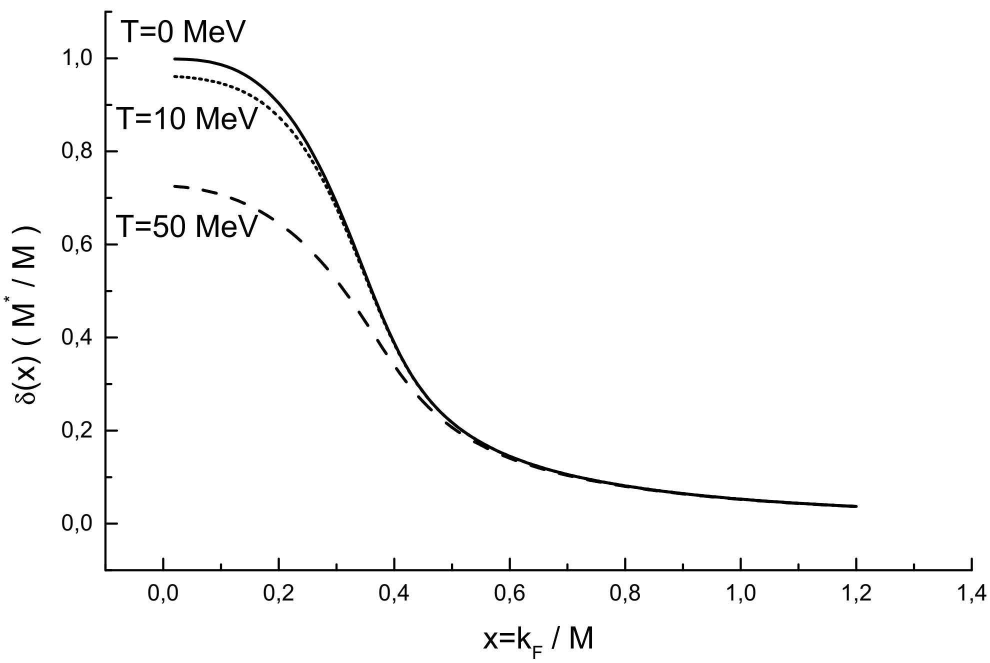

Figure 1: The effective nuclear mass

The solution of the equation (5) help us to define the parameter $\delta = m_{eff}/m$. The term m_{eff} denotes fermion effective mass which for nucleons is written as $m_{eff} = M^*$whereas for leptons $m_{eff} = m$ thus $\delta = 1$. Fig. 1 shows the relation between the parameter δ and the dimensionless Fermi momentum x for three different temperatures $T = 0,\, 10,\, 50$ MeV. The simplest case corresponds to L2 parameter set [1]. In the relativistic mean filed theory it corresponds to $m_s = 520\, MeV$ and $g_s = 10.47$ what gives

$$v = \frac{g_s}{m_s^2}$$

The fermion number density, energy density and pressure inside the star are defined locally as quantum averages. One can calculate such quantum averages employing the following equation

$$< A >= \frac{1}{Z} Tr(e^{-\beta(\mathcal{H} - \sum_f \mu_f N_f)} A) \tag{7}$$

where A is an observable, $\mathcal{H}$ is the Hamiltonian of the system and

$$Z = Tr(e^{-\beta(\mathcal{H}-\sum_f \mu_f N_f)})$$

is a partition function. In this equation $\beta = 1/k_B T$. Let us now define some operators indispensable in our calculations: the fermion number operator

$$N_f = \sum_{\mathbf{k},\sigma} (c^+_{\mathbf{k},\sigma,f} c_{\mathbf{k},\sigma,f} - d^+_{\mathbf{k},\sigma,f} d_{\mathbf{k},\sigma,f}) \tag{8}$$

where the index f stands for neutrons, protons and electrons ($f = p, n, e$) and $c^+_{\mathbf{k},\sigma,f}$, $c_{\mathbf{k},\sigma,f}$ and $d^+_{\mathbf{k},\sigma,f}$, $d_{\mathbf{k},\sigma,f}$ are creation and annihilation operators for particles and antiparticles respectively, the fermionic Hamiltonian $\mathcal{H}$ (ignoring the zero-point energy)

$$\mathcal{H} = \sum_f \sum_{\mathbf{k},\sigma} \epsilon_{\mathbf{k},f} (c^+_{\mathbf{k},\sigma,f} c_{\mathbf{k},\sigma,f} + d^+_{\mathbf{k},\sigma,f} d_{\mathbf{k},\sigma,f}) \tag{9}$$

with $\epsilon_{\mathbf{k},f} = c\sqrt{\hbar^2 k^2 + m_f^2 c^2}$ and the pressure with an isotropic distribution of momenta given by

$$P_f = \frac{1}{3} \sum_f \sum_{\mathbf{k},\sigma} \hbar k v_{\mathbf{k},f} (c^+_{\mathbf{k},\sigma,f} c_{\mathbf{k},\sigma,f} + d^+_{\mathbf{k},\sigma,f} d_{\mathbf{k},\sigma,f}) \tag{10}$$

where velocity equals $v_{\mathbf{k},f} = \hbar k c^2/\epsilon_{\mathbf{k},f}$. The mean number of fermions is determined by the following equation

$$< c^+_{\mathbf{k},\sigma,f} c_{\mathbf{k},\sigma,f} >= \frac{1}{\exp(\beta(\epsilon_{\mathbf{k},f} - \mu_f)) + 1} \tag{11}$$

where μ_f stands for the fermion chemical potential. Neutrons, protons and electrons are in β-equilibrium which can be described as a relation among their chemical potentials

$$\mu_p + \mu_e = \mu_n \tag{12}$$

where μ_p, μ_n and μ_e stand for proton, neutron and electron chemical potentials respectively. If the electron Fermi energy is high enough (greater then the muon mass) in the neutron star matter muons start to appear as a result of the following reaction

$$e^- \rightarrow \mu^- + \nu_e + \overline{\nu_\mu} \tag{13}$$

The chemical equilibrium between muons and electrons can be described by the condition

$$\mu_\mu = \mu_e \tag{14}$$

The equation (12) together with the charge neutrality $n_e + n_\mu = n_p$ allows us to determine the equation of state in terms of only one parameter x_n. It defines

the dimensionless Fermi momentum of a neutron $x_n = (\hbar k_n)/(m_n c)$. Using the stated above conditions and the equation

$$\mu_f = m_f c^2 (1 + x_f^2)^{1/2} \tag{15}$$

the relations between $x_n = x$ and x_p can be obtained
In the macroscopic limit an integral is allowed to replace a sum

$$\sum_{\mathbf{k}} \rightarrow \frac{V}{(2\pi)^3} \int d^3k \tag{16}$$

and for each fermion the quantum averages n_f representing the particle number density $n_f =< N_f > /V$, ε_f the energy density and P_f the pressure can now be written as

$$n_f(\mu_f, T) = n_0 \Theta(r, y) \tag{17}$$

$$\varepsilon_f(\mu_f, T) = c^2 \rho(\mu_f, T) = \varepsilon_0 \chi(r, y) \tag{18}$$

$$P(\mu_f, T) = P_0 \Phi(r, y) \tag{19}$$

The forms of these quantum averages are determined by the functions $\Theta(r, y)$, $\chi(r, y)$ and $\Phi(r, y)$ which are presented below.

$$\begin{aligned} \Phi(r, y) &= \frac{1}{3\pi^2} \int_0^\infty \frac{z^4 dz}{\sqrt{z^2 + \delta^2 y^2}} \{ \frac{1}{\exp(\sqrt{z^2 + \delta^2 y^2} - ry) + 1} \\ &+ \frac{1}{\exp(\sqrt{z^2 + \delta^2 y^2} + ry) + 1} \} \end{aligned} \tag{20}$$

$$\begin{aligned} \Theta(r, y) &= \int_0^\infty z^2 dz \{ \frac{1}{\exp(\sqrt{z^2 + \delta^2 y^2} - ry) + 1} \\ &- \frac{1}{\exp(\sqrt{z^2 + \delta^2 y^2} + ry) + 1} \} \end{aligned} \tag{21}$$

$$\begin{aligned} \chi(r, y) &= \frac{1}{\pi^2} \int_0^\infty dz \sqrt{z^2 + \delta^2 y^2} \{ \frac{1}{\exp(\sqrt{z^2 + \delta^2 y^2} - ry) + 1} \\ &+ \frac{1}{\exp(\sqrt{z^2 + \delta^2 y^2} + ry) + 1} \} \end{aligned} \tag{22}$$

with the following dimensionless variables $\delta = m_{eff}/m$, $y = mc^2/k_B T$, $z = \hbar kc/k_B T$ and $r = \mu_f/mc^2$. The forms of the dimensionless variables are the same as those used by Weldon in his work [5], [6]. The fermion chemical potential μ_f is given by the relation (15). Mutual relations between y and temperature as well as between r and μ_f result in dependence of functions Θ, Φ and χ on the dimensionless Fermi momentum x and the temperature T.

When the temperature equals zero the Shapiro for result free nucleons can be reproduced [9]

$$\Phi(x,0) = \frac{1}{8\pi^2}\{x\sqrt{1+x^2}(2x^{2/3}-1) + \ln(x+\sqrt{1+x^2})\} \tag{23}$$

which in the nonrelativistic limit $x << 1$ yields

$$\Phi(x,0) \to \frac{1}{15\pi^2}x^5 \tag{24}$$

and the equation of state takes the form of the polytrope $\Gamma = 5/3$. The forms of the functions Θ, χ and Φ indicate their relations with the functions $H_n(r,y)$ and $G_n(r,y)$ which are used in order to evaluate thermodynamic properties of the matter [7]

$$\begin{aligned} H_n(r,y) &= \int_0^\infty \frac{z^{n-1}dz}{\sqrt{z^2+\delta^2y^2}}\{\frac{1}{\exp(\sqrt{z^2+\delta^2y^2}-ry)+1} \\ &+ \frac{1}{\exp(\sqrt{z^2+\delta^2y^2}+ry)+1}\} \end{aligned} \tag{25}$$

$$\begin{aligned} G_n(r,y) &= \int_0^\infty z^{n-1}dz\{\frac{1}{\exp(\sqrt{z^2+\delta^2y^2}-ry)+1} \\ &- \frac{1}{\exp(\sqrt{z^2+\delta^2y^2}+ry)+1}\} \end{aligned} \tag{26}$$

The case where the interaction in the Lagrange function (1) is neglected (free nucleons) is equivalent to the one where δ in equations (25,26). These two terms in both equations (25,26) correspond to the contribution of particles and antiparticles, respectively and the functions $H_n(r,y)$ and $G_n(r,y)$ can be written as

$$\begin{aligned} H_n(r,y) &= h_n(r,y) + h_n(-r,y) \\ G_n(r,y) &= g_n(r,y) - g_n(-r,y) \end{aligned} \tag{27}$$

Both the pressure P_f and the energy density ε_f of the fermion system can be expressed with the use of the functions presented above

$$P_f = \frac{1}{3\pi^2}P_0(\frac{\lambda}{\lambda_T})^4\{H_5(r_p,y_p) + H_5(r_n,y_n) + H_5(r_e,y_e)\} \tag{28}$$

where $P_0 = (m_f c^2)/\lambda^3$, the fermion Compton wavelength $\lambda = \hbar/(m_f c)$ and $\lambda_T = (c\hbar)/(k_B T)$

$$\begin{aligned} \varepsilon_f &= \frac{1}{\pi^2}P_0(\frac{\lambda}{\lambda_T})^4\{H_5(r_p,y_p) + H_5(r_n,y_n) + H_5(r_e,y_e) \\ &+ H_3(r_n,y_n) + H_3(r_p,y_p) + H_3(r_e,y_e)\} \end{aligned} \tag{29}$$

Our first step is to find the pressure and energy density for nucleons and muons ($\delta = 1$) which corresponds to the nonrelativistic limit of the functions $G_n(r, y)$ and $H_n(r, y)$. Such a limit means either the case of large mass or low temperature. Introducing the new variable $\omega = \exp(y - \sqrt{x^2 + y^2})$ the following forms of the functions are achieved

$$h_5(r, y) = \int_0^1 \frac{(-\ln\omega)^{3/2}(2y\delta - \ln\omega)^{3/2} d\omega}{e^{y(\delta - r)} + \omega} \tag{30}$$

$$g_5(r, y) = \int_0^1 \frac{(-\ln\omega)^{3/2}(2y\delta - \ln\omega)^{3/2}(y\delta - \ln\omega) d\omega}{e^{y(\delta - r)} + \omega} \tag{31}$$

The calculation of these integrals has been performed on the basis of the method presented by Weldon in his work [5], [6]. Making use of the fact that $|\ln \frac{\omega}{2y\delta}| < 1$ in this approximation and expanding the numerators under that assumption, the functions h_5 and g_5 can be written in the form of

$$h_5(r, y) = (2y\delta)^{3/2} \sum_{k=0}^{\infty} \frac{\Gamma(\frac{5}{2})}{(2\delta y)^k \Gamma(\frac{3}{2} - k) k!} \int_0^1 \frac{(-\ln\omega)^{3/2+k} d\omega}{e^{y(\delta - r)} + \omega} \tag{32}$$

$$g_5(r, y) = (2y\delta)^{3/2} \sum_{k=0}^{\infty} \frac{\Gamma(\frac{5}{2})}{(2y\delta)^k \Gamma(\frac{3}{2} - k) k!} \int_0^1 \frac{(-\ln\omega)^{3/2}(2y\delta - \ln\omega)^{3/2} d\omega}{e^{y(\delta - r)} + \omega} \tag{33}$$

Having integrated the obtained equations term by term the final forms of the function emerge:

$$h_5(r, y) = (2y\delta)^{3/2} \Gamma(\frac{5}{2}) \sum_{k=0}^{\infty} \frac{\Gamma(\frac{5}{2} + k)}{\Gamma(\frac{5}{2} - k) k!} (\frac{1}{2y\delta})^k Li_{k+5/2}(-e^{y(r-\delta)}) \tag{34}$$

$$\begin{aligned} g_5(r, y) \quad = \quad & (2y\delta)^{3/2} \Gamma(\frac{5}{2}) \sum_{k=0}^{\infty} \frac{1}{\Gamma(\frac{5}{2} - k) k!} (\frac{1}{2y\delta})^k \\ & (y\delta Li_{k+5/2}(-e^{y(r-\delta)}) \Gamma(\frac{5}{2} + k) + \Gamma(\frac{7}{2} + k) Li_{7/2+k}(-e^{y(r-\delta)})) \end{aligned} \tag{35}$$

In order to calculate the contribution of electrons to the total pressure P_f and the energy density ε_f, the relativistic case should be considered. In this very case the variable y tends to zero. It is necessary to calculate the mentioned above functions $H_n(r, y)$ and $G_n(r, y)$ in the relativistic limit, where again the method used by Weldon in [5], [6] has been involved. These functions obey the recursion relations

$$\begin{aligned} \frac{dG_{n+1}}{dy} &= lrH_{n+1} - \frac{y}{n} G_{n-1} + \frac{y^2 r}{n} H_{n-1} \\ \frac{dH_{n+1}}{dy} &= \frac{r}{y} G_{n-1} - \frac{y}{n} H_{n-1} \end{aligned} \tag{36}$$

Thus the functions $H_1(r,y)$ and $G_1(r,y)$ together with the initial conditions

$$\begin{aligned} G_n(0,0) &= 0 \\ H_n(0,0) &= 2(1-2^{2-n})\Gamma(n-1)\zeta(n-1) \end{aligned} \tag{37}$$

are sufficient to determine the functions $H_5(r,y)$ and $H_3(r,y)$ which in turn are indispensable to calculate the pressure and energy density. The identity

$$\frac{1}{\exp y+1} = \frac{1}{2} - 2\sum_{0}^{\infty}\frac{y}{y^2+\pi^2(2n+1)^2} \tag{38}$$

originated from Dolan and Jackiw [8] gives us the possibility to write the functions H_1 and G_1 as

$$\begin{aligned} H_1(r,y) &= -\int_0^\infty \frac{dz}{\sqrt{(z^2+y^2)}} \\ &- 4\sum_{n=0}^{\infty}\int_0^\infty \frac{[z^2+y^2(1-r^2)+(2n+1)^2\pi^2]dz}{[z^2+y^2(1-r^2)+(2n+1)^2\pi^2]^2+4\pi^2r^2y^2(2n+1)^2} \end{aligned} \tag{39}$$

$$G_1(r,y) = -4ry\sum_{n=0}^{\infty}\int_0^\infty \frac{[z^2+y^2(1-r^2)-(2n+1)^2\pi^2]dz}{[z^2+y^2(1-r^2)+(2n+1)^2\pi^2]^2+4\pi^2r^2y^2(2n+1)^2} \tag{40}$$

The integrands in these equations are multiplied by the convergent factor $z^{-\varepsilon}$ and after its expansion as a power series in y the term by term integration is performed. In the next step the summation over n is carried out. In the last stage the limit $\varepsilon \to 0$ enables us to obtain the final result which in the first approximation achieves the form of

$$H_1(r,y) = -(\gamma + \ln(\frac{y}{\pi})) \tag{41}$$

$$G_1(r,y) = ry \tag{42}$$

Knowing the form of functions $H_1(r,y)$ and $G_1(r,y)$ and the initial conditions (37) it is possible to calculate the functions $H_3(r,y)$, $H_5(r,y)$, $G_3(r,y)$

$$H_3(r,y) = \frac{1}{8}(2r^2+2\gamma-1)y^2 + \frac{1}{4}y^2\ln(y/\pi) \tag{43}$$

$$H_5(r,y) = \frac{1}{768}(8r^4-24r^2-12\gamma+9)y^4 - \frac{1}{64}y^4\ln y/\pi \tag{44}$$

$$G_3(r,y) = \frac{1}{12}r(2r^2-3)y^3 \tag{45}$$

These functions are employed to express the electron pressure and energy density according to the equations (28) and (30). Consequently the relation between the total pressure P_f being the sum of the leptons and nucleons pressures and the dimensionless Fermi momentum x is presented in Fig.2. The curves in

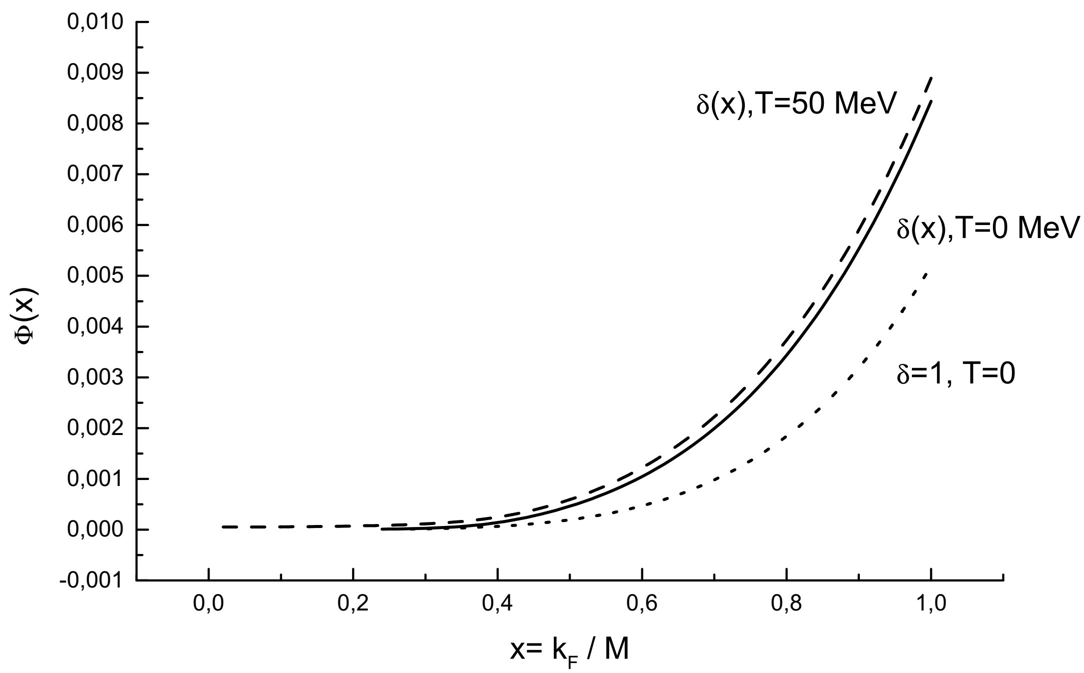

Figure 2: The pressure $\Phi(x)$ as the function of the Fermi momentum $x = p_F/mc$

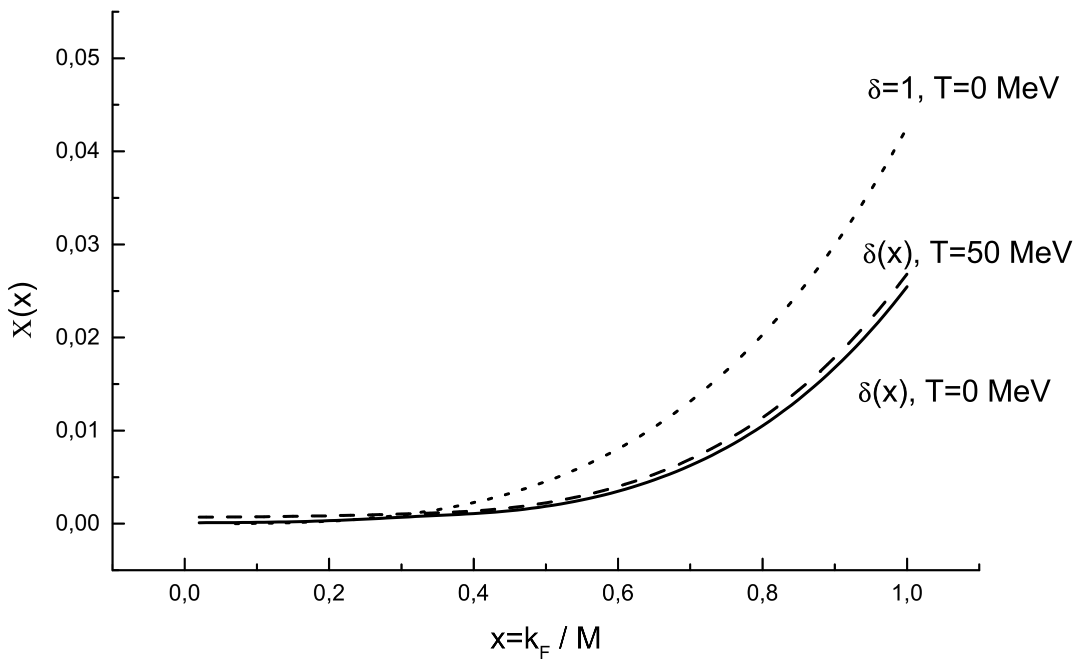

Figure 3: The energy density $\chi(x)$ as the function of the Fermi momentum $x = p_F/mc$

Fig, 2 are parameterized by the temperature and δ. The curves for the zero temperature limit are obtained for two cases with and without $(v = 0)$ the presence of interaction. The curve for the temperature $T = 50\,MeV$ is the case with interactions.

Analogous description can be made analyzing the connection between the energy density χ and the parameter x. See Fig.3.

3 The neutron star

The most important factor determining the structure of a neutron star is the equation of state. This very equation makes possible to describe a static spherical star solving the OTV equation.

$$\frac{dm(r)}{dr} = 4\pi r^2 \rho(r) \tag{46}$$

$$\frac{dP(r)}{dr} = -\frac{G}{r^2}(\rho(r) + \frac{P(r)}{c^2})\frac{(m(r) + \frac{4\pi}{c^2}P(r)r^3)}{(1 - \frac{2Gm(r)}{c^2 r})} \tag{47}$$

Having solved this equation the pressure $P(r)$, mass $m(r)$ and density $\rho(r)$ were obtained. To achieve the total radius R of the star the fulfillment of the condition $P(R) = 0$ is necessary which allows to determine the total gravitational mass of the star $M(R)$.

Introduction of the dimensionless variable ξ which is connected with the variable r by the relation $r = a\xi$ ($a = 1$ km) enables us to define the functions $P(r)$, $\rho(r)$ and $m(r)$ in the following form

$$\rho(r) = \rho_c f^{\frac{3}{2}}(\xi) \tag{48}$$

$$P(r) = P_c u(\xi) \tag{49}$$

$$m(r) = M_0 v(\xi) \tag{50}$$

Some more parameters, namely

$$\lambda = \frac{GM_o\rho_c}{P_c a} \tag{51}$$

$$\omega = \frac{P_c}{c^2\rho_c} \tag{52}$$

and

$$\tau = 3\frac{M_c}{M_o}, \qquad M_c = \frac{4}{3}\pi\rho_c a^3 \tag{53}$$

are also needed to achieve the useful form of the OTV equation

$$\frac{du}{d\xi} = -\lambda(f(\xi)^{\frac{3}{2}} + \omega u(\xi))\frac{v(\xi) + \omega\tau u(\xi)\xi^3}{\xi^2(1 - \frac{r_g}{a}\frac{v(\xi)}{\xi})} \tag{54}$$

$$\frac{dv}{d\xi} = \tau f(\xi)^{\frac{3}{2}}\xi^2 \tag{55}$$

with

$$r_g = \frac{2GM_o}{c^2} \tag{56}$$

These equations can be solved specifying the central neutron energy density being the energy density for $r = 0$.

The equation of state is the function of the temperature and the neutron chemical potential which changes with the radius r. Therefore the changes of the radius influence the parameters of the star. Using the results obtained in previous chapter it is now possible to write the functions $P(r)$ and $\rho(r)$ in the form

$$\rho(\mu, T) = \rho_0\chi(x, T) = \rho_c f^{\frac{3}{2}}(\xi) \tag{57}$$

$$P_0\Phi(x, T) = P_c u(\xi) \tag{58}$$

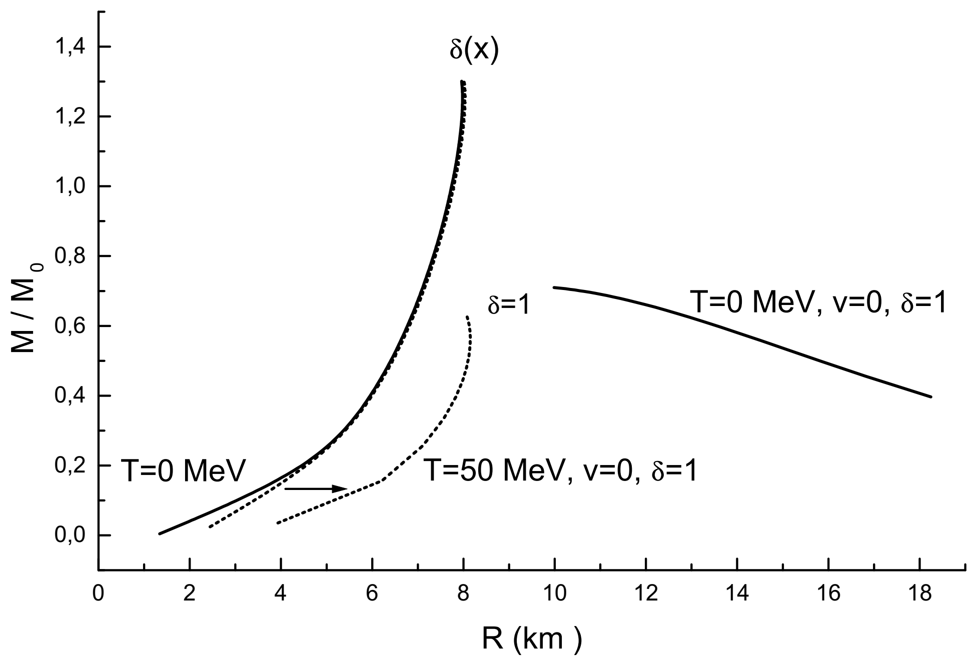

Figure 4: The R-M diagram for the neutron star with interaction and without ($v = 0$).

and the variable x can be obtained

$$x = \chi^{-1}(\frac{\rho_c}{\rho_0} f^{\frac{3}{2}}(\xi)) \tag{59}$$

$$P_c u(\xi) = P_0 \Phi(\chi^{-1}(\frac{\rho_c}{\rho_0} f^{\frac{3}{2}}), T) \tag{60}$$

The function $u(\xi)$ takes the form

$$u(\xi) = \frac{P_0}{P_c} \Phi(\chi^{-1}(\frac{\rho_c}{\rho_0} f^{\frac{3}{2}}(\xi)), T). \tag{61}$$

The solution of the Oppenheimer-Volkoff-Tolman equation depicts the mass-radius relation. Fig.4 allows us to compare the zero-temperature mass versus radius relation with the other temperature cases with and without ($v = 0$) interaction .

Fig.5. shows the changes of the radius as a function of the neutron density ρ_c in the center of the star.

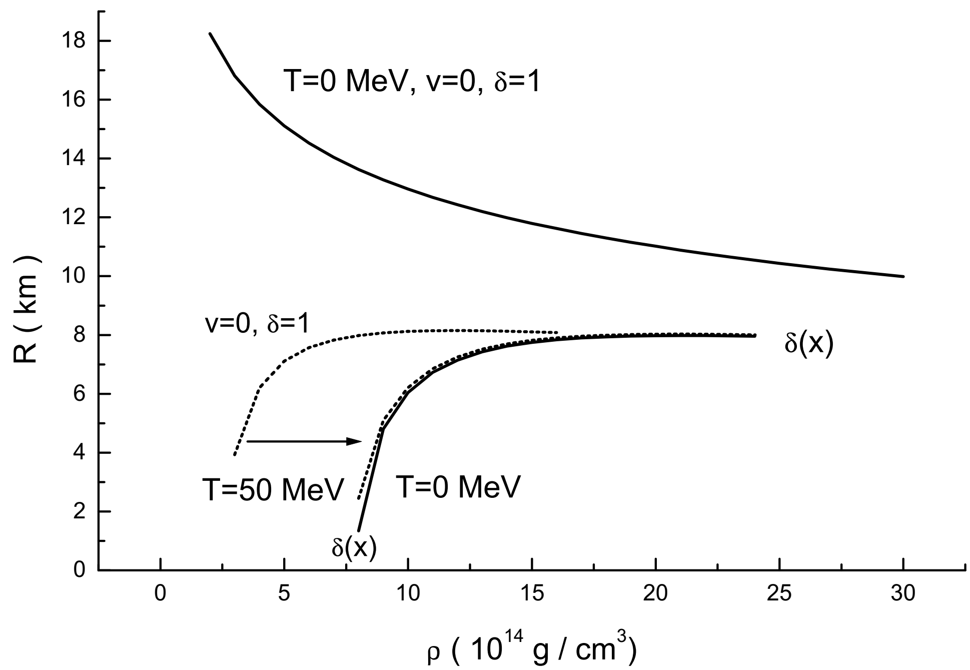

Figure 5: The neutron star radius $R(km)$ as a function of the neutron density ρ_c in the center of the star.

4 Conclusions

Herein presented solutions of the Oppenheimer-Volkoff-Tolman equations of hydrostatic equilibrium concern hot neutron stars. The neutron star matter in this model consists of neutrons, protons and leptons (electrons,muons) being in β- equilibrium under the assumption that the temperature is different from zero. It varies from 0 to 50 MeV. The objective of our work was to study the influence of the temperature on the main parameters of a neutron star. In order to achieve the proper form of the equation of state, which is determined only by the neutron Fermi momentum, it is necessary to calculate either the low temperature or the high temperature expansion of the integrals (**??**) and (27). This very simple model presents a few global properties of the hot neutron star such as the mass and the size.The parameters of neutron stars obtained in this simplified model considering zero temperature and cases of finite temperatures vary from one another. In each of the mentioned above cases stars with the same energy density inside are considered. However, their baryon numbers are different which makes each of them a different star with specific baryon number. In this situation we do not deal with the thermal evolution of one star with conserved baryon number but several separate cases. The star whose parameters at the temperature of 50 MeV are as follows: for $\delta = 1$ $M = 0.62\, M_{\odot}$ $R = 8.08\, km$, for $\delta \neq 1$ $M = 1.3\, M_{\odot}$, $R = 8.00\, km$ At zero temperature limit the star is characterized by the mass $0.7\, M_{\odot}$ and the radius $10.54\, km$ for $\delta = 1$ and the mass $1.24\, M_{\odot}$ and radius $7.98\, km$ for $\delta \neq 1$. It is obvious that some more extended models e.g. those including boson fields should be examined. Therefore we would like to continue the subject in our next papers

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